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Some Characteristics of Digital Vasomotor Activity

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ABSTRACT

Size and latency of responses to a series of tones, spontaneous fluctuations, and habituation in finger volume and pulse volume were studied in 19 healthy young soldiers by means of pneumoplethysmography. The results indicate that relationships among vasomotor measures differ from those reported for skin conductance measures. Thus, in contrast to what has been shown for skin conductance, no correlation was found between habituation and number of spontaneous fluctuations, and the variability of the first response to the tones did not differ from the variability of the following responses. Auditory stimulation did not increase the number of spontaneous fluctuations. There were highly significant correlations between spontaneous fluctuations during rest and stimulation periods. No significant correlations were obtained between pulse volume responses to an arithmetic task and responses to tone stimuli. Some differences in pattern of relationships were obtained between finger and pulse volume measures. Initial responses in finger volume were related to other response size measures, whereas this was not the case for pulse volume. Response latency increased during the auditory stimulation for pulse volume, but not for finger volume.

DESCRIPTORS: Finger volume, Pulse volume, Responses to tones, Habituation, Spontaneous fluctuations. (L. Lidberg)

Possibly because these two indicators of autonomic activity are technically relatively simple to measure, the interrelationships of various aspects of autonomic activity and especially size of response, response latency, habituation, and number of spontaneous fluctuations have previously been studied mainly in skin conductance and heart rate.

Habituation of *skin conductance* responses shows a significant negative correlation with number of spontaneous fluctuations (Koepeke & Pribram, 1966; Johnson, 1963; Lader & Wing, 1966). Further, the number of spontaneous fluctuations is significantly and positively correlated with the magnitude of response to the first of a series of stimuli (Johnson, 1963; Stern, 1966), and with number of responses occurring during a series of tones (Stern, Stewart, & Winokur, 1961).

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Some authors have found that magnitude of response to tone stimuli in skin conductance is unrelated to number of spontaneous fluctuations (Wilson & Dykman, 1960; Koepke & Pribram, 1966), while others have reported positive correlations between number of spontaneous fluctuations and the mean response to tone stimuli (Johnson, 1963). The response to the first tone has been found to be "exceptional" (Lader, 1964) and significantly more variable than the other responses (Montagu, 1963). It may be noted that these authors obtained a significant negative correlation between the regression coefficient and the calculated value of the response to the first tone, indicating that subjects with large initial responses had greater habituation.

With respect to measurements of *heart rate*, the corresponding correlations are less consistent and not always in the same direction as with measurements of skin conductance (Johnson, 1963). Later studies have disclosed a conspicuous dissociation between number of spontaneous fluctuations for skin conductance and *digital pulse volume*. Lader (1965) found that number of spontaneous pulse volume fluctuations increased during periods of drowsiness induced by cyclobarbitone, whereas the number of spontaneous skin conductance fluctuations decreased. A dissociation between the response trends in skin conductance and in vasomotor responses during drowsiness was noted by McDonald, Johnson, and Hord (1964).

Roessler, Alexander, and Greenfield (1963) reported an approximately linear relationship between response magnitude and stimulus intensity both for finger volume and for skin conductance. Further for finger volume the same authors (Greenfield, Alexander, & Roessler, 1963) obtained no relationship between response latency and stimulus intensity, possibly indicating a lack of relationship between response magnitude and response latency. According to these authors this is the case also with respect to skin conductance.

It is obvious that the relationships found between different characteristics of skin conductance cannot be applied to vasomotor activity. The purpose of the present study was to analyze measures obtained by two different plethysmographic techniques in order to provide a foundation for further investigations of "emotional stress" in digital vasomotor activity under conditions of confinement.

Method

Subjects

Nineteen soldiers, 19-21 years old, served as subjects. Participation was voluntary and the *Ss* were paid. They were in good physical and mental health.

Measurement of Finger Volume

A pressure transducer of capacitor microphone type (Elema EMT 32) was connected to a plastic oncometer cuff via a rigid plastic tube. The cuff was mounted airtight on the fourth finger of the *Ss* left hand by means of plasticine mixed to five percent with zinc oxide. Rapid pulse deflections were eliminated in the recordings by using a low-pass electronic filter (3 dB loss at approximately 0.5 Hz).

Measurement of Pulse Volume

A pressure transducer of piezoelectric type (Elema EMT 510, see Lund, 1964) was connected to a plastic oncometer cuff via a rigid plastic tube. The cuff was

mounted airtight on the S's left index finger as described above. The apparatus had a time constant of 2 sec and a high frequency limit of 500 Hz. The volume of the finger tip inside the oncometer cuff was measured in mm³ by a water displacement method and the size of the finger nail was measured, as comparisons between Ss were planned (Lader, 1967). The size of the finger nails, representing an inert material, varied from 2.8 to 1.3 percent of the total volume.

Recording Instrument

An ink-writer of Elmquist fast-response type (Mingograf 81) was used.

Procedure

The Ss came to the laboratory in the afternoon, after their normal duties. They rested for half an hour in an examination chair in a quiet room, in which the temperature varied between 21.5°C and 23.5°C. The finger temperature of the Ss, measured by a thermistor device, varied between 21.5°C and 34.8°C at the beginning of the experiment proper. A constant, faint indirect light was used. The recording apparatus was kept in an adjoining room, which had a small window through which the experimenter could observe the S, who was alone in his room during the recordings. The S's left arm and hand were placed on a soft support with the arm in a resting position, so that the fingers were on a level with the sternal angle. Two EKG electrodes were applied to the right ankle.

The procedure was explained to the S, and several deep inspirations were practiced in order to make more reliable the later recording of the digital inspiratory vasoconstriction reflex. The recording was then started, after which all instructions to the S were given from a tape recorder via a loud-speaker, with echo-effects eliminated. The 3 main experimental periods reported are: (a) an initial rest period of 10 min (Period I), (b) a tone stimulation period (Period II), and (c) a final rest period of 5 min (Period III).

During Period II 11 sine wave tone stimuli, 1000 Hz, approximately 100 dB and 1 sec duration, were administered through the loud-speaker. The intervals between the tones were randomized and varied between 35 and 60 sec. Two min rest followed the tone stimulation period, after which the S took 3 distinctly spaced maximal deep inspirations, followed by another 2 min rest. Then 2 simple arithmetic tasks were given ($13 + 21$ and $16 + 33$). After another 2 min rest the S was informed that a short, harmless but painful electric shock was to be given through the right leg EKG electrodes, the function of which had not been explained before. A shock of 4 mA with a duration of 0.4 sec was given. Responses and fluctuations in this part of the experiment could not be evaluated, due to a marked vasoconstriction. The S was then informed that the experiment proper was finished, but that resting levels in the recording were being obtained and he was shown how to relax. After 5 min rest (Period III) the continuous recording was terminated.

Quantification of Results

Finger Volume

Any observable decrease of finger volume occurring between 1.6 and 10 sec from the onset of each tone stimulus was considered as a *response*. Decreases within 1.5 sec were disregarded. Regarding this response latency criterion, see Stewart, Stern, Winokur, and Fredman, 1961. The response was quantified as the

difference, in mm of pen deflection, between the maximal deflection and the mean level during the 10 sec preceding the stimulus. This value was then corrected for amplification and the volume of finger tip inserted into the cuff. Each response was expressed as a percentage of the mean response to 3 maximal deep inspirations which was used as an estimate of the individual maximal response.¹ This was made in order to correct for the individual differences in range of response (cf. Paintal, 1951; Lykken, Rose, Luther, & Maley, 1966).

The mean response to all tones, the response to the first tone, and the sum of the first 3 responses are reported. The response to the first tone is of interest as startle response (see Lader & Wing, 1966, p. 11). The sum of the first 3 responses was used as an estimate of initial responsivity.

Response latency was measured as the time from the onset of the stimuli to an observable decrease of volume.

A *spontaneous fluctuation* was considered to have occurred if there was a deviation of the curve similar in shape to that obtained in response to a known stimulus and within the range of the individual's responses to auditory stimuli. For the response to be included the effects of an earlier response had to have subsided. Thus, large, slow variations in the curve were not counted as spontaneous fluctuations. The retest reliability with an interval of one month was .96 for this measure.

Pulse Volume

Any observable decrease of the pulse volume occurring between 1.6 and 10 sec from the onset of a tone stimulus was considered as a *response*. Changes occurring within 1.5 sec were disregarded (response latency criterion).

The responses were quantified as the difference, in mm pen deflection, between the mean of the 3 smallest consecutive deflections during the 10 sec preceding the stimulus, and the mean of the 3 smallest deflections during the 10 sec following the stimulus. The difference was expressed as a percentage of the mean of the 3 smallest deflections during the 10 sec preceding the stimulus. This method of quantifying a response gives a fair approximation to the differential logarithmic method used by Lader (1965).

The mean response to all tones, the response to the first tone, and the sum of the first 3 responses are reported.

Response latency was measured as the time from onset of the stimulus to an observable decrease in the amplitude of the pulse volume deflections.

Pulse volume amplitude during Periods I and III was sampled at intervals of 30 sec and expressed as the mean pulse volume.

Pulse volume reaction to the announcement of an arithmetic task (*mental task response*) was measured as the difference between the mean of the 3 consecutive pulse volume deflections occurring immediately before the instruction, and the mean of the 3 smallest pulse volume deflections after the instruction, but before the answer was given. The difference was expressed as a percentage of the mean of the 3 pulse volume deflections occurring immediately before the instruction.

A *spontaneous fluctuation* was counted when a decrease in amplitude of at least 30 percent of the prestimulus amplitude took place within a period of 4 sec. Thus, only fluctuations in amplitude similar to responses to auditory stimuli were taken into account. This criterion was deemed necessary in view of the baseline fluctuations occurring with the time-constant used (2 sec).

¹ Lund, F. Personal communication, 1966.

To avoid counting double-responses, an additional criterion was that the median of the 3 smallest consecutive beats within 8 sec after the start of the amplitude decrease should not be larger than 70 percent of the median of the 3 smallest beats within 10 sec before the decrease. The retest reliability with an interval of one month was .97 for this measure. The interjudge reliability was .84.

For pulse volume (as well as finger volume) spontaneous fluctuations were counted during Periods I, II, and III. In the stimulation period, such fluctuations were counted in the 1.6 sec period after the onset of the tone as well as after a response had subsided.

When comparing the number of spontaneous fluctuations during the 3 periods, a correction factor was used to make up for differences in time during the 3 periods. This factor was 1.00 for Period I, 1.53 for Period II, and 2.00 for Period III.

Habituation

For both finger and pulse volume, habituation of responses was estimated by the Kendall rank correlation coefficient tau (Kendall, 1962; Levander, Lidberg, & Schalling, 1969). Positive values correspond to decreasing size of responses.

The means of the responses both in finger and pulse volume showed a linear relationship against log stimulus number in our data. The method of estimating habituation used by Montagu (1963) was therefore also applied. Acting on the suggestion by Lader (1964), Montagu used a correction in order to remove the dependence of the regression line on the intercept (a) of the Y-axis. This corrected regression coefficient (b') was regarded as an estimate of the absolute rate of habituation.

Results and Discussion

Product moment correlation coefficients were computed between the different measures obtained. The pattern of results was essentially the same when rank correlations were computed.

Finger Volume

Size of Response. As seen from Table 1, significant positive correlations were obtained among the various response size measures. Of course these measures have some common variance.

TABLE 1
Product moment correlations among the finger volume variables

Variables	Periods	Correlation coefficients					
		1	2	3	4	5	6
1. Mean response to all tones	II	—					
2. Response to first tone	II	.59**	—				
3. Sum of the first 3 responses to tones	II	.57**	.87**	—			
4. Mean response latency	II	-.01	.38	-.16	—		
5. Spontaneous fluctuations	I	-.35	-.36	-.37	-.18*	—	
6. Spontaneous fluctuations	II	-.34	-.35	-.39	-.29	.82**	—
7. Spontaneous fluctuations	III	-.06	-.14	-.16	-.48*	.74**	.63**

* $p < .05$ (.41).

** $p < .01$ (.56).

TABLE 2

Means and standard deviations of spontaneous fluctuations during Periods I, II, and III, and differences between the periods for 16 subjects for whom complete recordings in all periods were obtained

Periods	Finger Volume		Pulse Volume	
	Means	SDs	Means	SDs
I	6.13	4.37	4.13	3.28
II	5.63	4.35	4.20	4.20
III	7.50	5.62	4.25	3.96
I-II	0.50	2.42	-0.07	2.56
II-III	-1.87	5.40	-0.05	3.74
I-III	-1.37	3.16	-0.12	2.73

Response Latency. Response latency showed no significant correlations with the response size measures (Table 1). There was a significant negative correlation between response latency and the number of spontaneous fluctuations during Periods I and III. This is in line with findings for skin conductance (Lacey & Lacey, 1958; Sternbach, 1960; Koepke & Pribram, 1966).

Spontaneous Fluctuations. The mean numbers of spontaneous fluctuations during Periods I, II, and III are shown in Table 2. (As fluctuations in pulse volume could not be evaluated for 3 Ss, due to a marked vasoconstriction, the computations were based on recordings from the 16 Ss for whom evaluation was possible during all 3 periods for both methods.) There were significantly more spontaneous fluctuations during the final rest period than during the stimulation period ($p < .01$). It is worth noting that no increase was induced by the tone stimulation, as has been found for skin conductance (e.g. by Lader & Wing, 1966). The number of spontaneous fluctuations during the stimulation period was even somewhat lower than in the rest periods.

The correlations between the number of spontaneous fluctuations during Periods I, II, and III were highly significant (Table 1).

Pulse Volume

Size of Response. As seen from Table 3, significant positive intercorrelations were obtained among the various response size measures, with the exception that the response to the first tone was not significantly correlated with mean response to all tones.

The decrease in pulse volume occurring between the presentation of the first arithmetic task and the S's answer showed no significant correlation with other response size measures. (The vasoconstriction accompanying this answer persisted too long to make it possible to evaluate the response to the second arithmetic task presentation.) This lack of correlation between pulse volume response to a slight mental stressor like the arithmetic task and responses to tone stimuli is notable.

Response Latency. There were no significant correlations between response latency and the other pulse volume measures (Table 3).

The response latency increased toward the end of the stimulation period. The difference between the means of response latencies for the first 5 and the last 5 responses was significant ($t = 3.67$, $p < .01$). This is in accordance with what has been reported for skin conductance (Koepke & Pribram, 1966).

TABLE 3
Product moment correlations among the pulse volume variables

Variables	Periods	Correlation Coefficients								
		1	2	3	4	5	6	7	8	9
1. Mean response to all tones	II	—								
2. Response to first tone	II	.21	—							
3. Sum of the first 3 responses to tones	II	.48*	.72**	—						
4. Mean response latency	II	.06	.10	-.22	—					
5. Mental task response	II	-.20	-.19	-.21	-.23	—				
6. Spontaneous fluctuations	I	.13	-.24	-.22	-.28	.05	—			
7. Spontaneous fluctuations	II	-.02	-.29	-.15	-.17	-.16	.86**	—		
8. Spontaneous fluctuations	III	-.04	.54*	.02	-.21	.07	.73**	.67**	—	
9. Amplitude sampling	I	.45*	.21	.43	.28	.00	-.21	-.22	-.27	—
10. Amplitude sampling	III	.41	.17	.46*	.03	.02	-.25	-.64**	-.25	.89**

* $p < .05$ (.44).

** $p < .01$ (.56).

Spontaneous Fluctuations. There were no significant differences between the mean number of spontaneous fluctuations during Periods I, II, and III (Table 2). The correlations between the number of spontaneous fluctuations in the 3 periods were highly significant (Table 3).

Amplitude Samplings. There were highly significant positive correlations between the mean pulse volume amplitude during the 2 rest periods (Table 3). The correlations between the amplitude samplings and the response size measures were positive, as might be expected, and were significant or nearly significant except for the response to the first tone. The amplitude samplings were negatively although as a rule not significantly correlated with the number of spontaneous fluctuations.

Differences Between Pulse Volume and Finger Volume

From our results, it appears that the response to the first tone in finger volume is related to the general responsivity as estimated by the mean response to all tones, whereas this is not the case for pulse volume. In contrast to finger volume, there was an increasing response latency during auditory stimulation for pulse volume (cf. Levander et al., 1969). Response latency in finger volume, but not in pulse volume, tended to be shorter in Ss with many spontaneous fluctuations.

There was a tendency for Ss with many spontaneous fluctuations in finger volume during the first 2 periods to have lower response size. This is in accordance with the findings of Alexander, Roesler, and Greenfield (1963), although their results are not directly comparable with ours, as they studied both the amplitude and the different frequency ranges of spontaneous fluctuations. The corresponding correlations for pulse volume were also negative although much lower, except that the response to the first tone was significantly positively correlated with spontaneous fluctuations in the final rest period. The interpretation of this reversal of direction in the correlation in this case is not clear.

Similarities Between Finger and Pulse Volume

The sum of responses to the first 3 tones was related to the mean response to all tones for both finger and pulse volume, which indicates that the *Ss* tend to keep their relative positions in responsivity established early in the tone series. The variability of the first response for both finger and pulse volume did not differ significantly from the variability of the other responses, contrary to what has been reported for skin conductance by Montagu (1963).

Response latency showed no significant correlations to response size measures either for finger or pulse volume, which is in line with the assumption stated above, based on results by Greenfield et al. (1963). Comparisons between response latency for finger and pulse volumes respectively are subject to systematic errors due to the different time constant in the recording systems (see Levander et al., 1969).

There were as a rule no significant correlations between spontaneous fluctuations and the various response size measures. In contrast to what has been reported for skin conductance, especially with regard to initial responsivity, the direction of the correlations was consistently negative, indicating a tendency for individuals with many spontaneous fluctuations to have low response size. No relationships were obtained between habituation and spontaneous fluctuations (see below).

The findings are of interest in view of the assumption by Lader (1965) that the psychological meaning of vasomotor spontaneous fluctuations is different from that of skin conductance fluctuations.

In accordance with what has been reported for skin conductance by Johnson (1963) and for pulse volume by Lader (1965), the number of spontaneous fluctuations both for finger and pulse volume in the present data were highly correlated during the 3 experimental periods, indicating a moderate to high reliability for this measure.

Habituation

The tau estimates of habituation were significant for both finger and pulse volume responses (Levander et al., 1969). Both for finger volume and pulse volume, significant intercorrelations were obtained among the three habituation estimates (finger volume: tau with *b*, $-.81$; tau with *b'*, $-.74$; *b* with *b'*, $.85$, all $p < .01$; pulse volume: tau with *b*, $-.65$; *b* with *b'*, $.56$, both $p < .01$), with the single exception of the correlation between tau and *b'* for pulse volume ($-.11$).

For finger volume, the habituation estimates were not consistently correlated with other measures (Table 4). For pulse volume, in line with findings for skin conductance, habituation was greater in *Ss* with high initial responsivity as estimated by the response to the first tone and the sum of the first 3 responses (Table 4). There were highly significant correlations between *b'*, the habituation estimate in which correction for initial level was made, and the mean response to all tones as well as the amplitude samplings, indicating that *Ss* with large response size and those with large pulse volume amplitude tended to show slow habituation.

Large amplitude was also related to the tau estimate of habituation.

There were no significant correlations between number of spontaneous fluctuations and habituation, regardless of habituation estimates used, in contrast to what has been consistently found for skin conductance (Mundy-Castle & Kiever,

TABLE 4

Product moment correlations between the three habituation estimates (tau, b, and b') and other variables (response measures, spontaneous fluctuations, and amplitude samplings)

Greater habituation is indicated by positive values on tau and negative values on b and b'

Variables	Periods	Correlations with Habituation Estimates					
		Finger Volume			Pulse Volume		
		tau	b	b'	tau	b	b'
1. Mean response to all tones	II	-.26	.05	.59**	.13	.05	.91**
2. Response to first tone	II	.21	-.59**	-.11	.54*	-.62**	-.09
3. Sum of the first 3 responses to tones	II	.41	-.39	.16	.78**	-.70**	.31
4. Mean response latency	II	-.38	.31	-.19	-.21	.19	-.16
5. Spontaneous fluctuations	I	.07	-.16	-.09	-.13	.19	-.14
6. Spontaneous fluctuations	II	-.07	-.18	-.15	-.02	.14	-.25
7. Spontaneous fluctuations	III	.09	-.17	-.12	-.04	.27	.26
8. Amplitude sampling	I	—	—	—	.45*	-.03	.30
9. Amplitude sampling	III	—	—	—	.41	.12	.45*

* $p < .05$ (.44).

** $p < .01$ (.56).

1953; Koepke & Pribram, 1966) and for vasomotor activity (Stern, 1966). There was no significant correlation between the calculated a-value and the b-score.

The estimation of habituation by rank correlation methods, such as the Wilcoxon test (Davis, Buchwald, & Frankmann, 1955) or by means of Kendall's tau, greatly depends on the "smoothness" of the consecutive decrease in responses. This coefficient includes in itself not only the slope of an assumed regression curve, but also deviations of responses from the regression curve. One single exceptional response can thus have a great influence on the value of this habituation estimate even if all other responses are monotonously decreasing with increasing stimulus number. However, when using the slope of the regression line (responses on log stimulus numbers) as an estimate of habituation, a linearity is assumed that almost exclusively occurs in large pooled samples (Montagu, 1963).

Correction of the b-score for the Y-axis intercept has mostly been done on the basis of the finding of a high correlation between the first response (a) and the coefficient of regression of the responses. However, in the present data no significant correlation was obtained. The b-score gives a less reliable measure, when the slope of the regression line is steep, due to a smaller number of anchoring points for the regression line. The criterion of non-responses often used as an estimate of habituation in skin conductance is less appropriate for vasomotor measures, as responses tend to reappear after a series of non-responses (Hare, 1968).

Thus, the estimation of habituation offers great problems, and comparisons between estimates in different autonomic systems are questionable.

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